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Second order active-R filter with multiple feedback for different Q

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Abstract : A second order active-*R* filter with multiple feedback is proposed The negative feedback at inverting input of first op.amp through *R* *R*, and also feedback through noninverting input from inverting input of first op amp are introduced It gives three basic filter functions , Low pass, High pass and Band pass at different terminals It is suitable for high frequency operation, monolithic IC implementation. It gives high passband gain and high value of Q It can be used for narrow band as well as wide band filters functions The Q has lower limit ($Q \geq 0.02$)

Keywords : Second order filters, active-R, feedback, passband gain

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Active filters having active elements as operational amplifier (op amp) and only resistances, are called active-*R* filters. Active-*R* filters have received much attention due to their potential advantages in terms of miniaturization, ease of design and high frequency performance [1-2]. The op.amp shows the high frequency roll-off due to parasitic capacitance [3,4]. Various authors have proposed configuration for different filter functions without feedback at noninverting input [2, 4-9]. This article introduces a voltage-mode Active-*R* filter with multiple feedback This gives three filter functions, low pass, high pass and band pass at three terminals with high passband gain. It has lower limit on Q ($Q \geq 0.02$), which mainly depends on f_0; it does not limit input signal frequency. The circuit was designed and studied for different values of Q.

The single-pole model of op.amp. leads to complex gain and the transfer function shows op.amp. as an 'integrator' [3]. Using this approach, the analysis of this represented circuit gives the following transfer function at the three different terminals.

The voltage transfer function for low-pass filter

$$T_{LP}(s) = \frac{-(1/R_3)GB_1GB_2}{X_1S^2 + X_2S + X_3}, \tag{1}$$

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The voltage transfer function for band pass filter

$$T_{BP}(s) = \frac{-(1/R_3)\, GB_1S}{X_1S^2 + X_2S + X_3}, \tag{2}$$

The voltage transfer function for high pass filter

$$T_{HP}(s) = \frac{(1/R_3)\, GB_1GB_2\left[1 + (S^2/GB_1GB_2)\right]}{X_1S^2 + X_2S + X_3} \tag{3}$$

As $\left[s^2/GB_1\, GB_2\right] >> 1$,

$$T_{HP}(s) = \frac{(1/R_3)S^2}{X_1S^2 + X_2S + X_3} \tag{4}$$

where, $X_1 = \left((1/R_1) + (1/R_2) + (1/R_3)\right)$,

$$X_2 = GB_1/R_2, \quad X_3 = GB_1.GB_1/R_1 .$$

The circuit was designed using coefficient matching technique *i.e.* by comparing these transfer functions with general second order transfer function [4].

The general second order transfer function is given by

$$T(s) = \frac{\alpha_2 S^2 + \alpha_1 S + \alpha_0}{S^2 + (\omega_0 / Q)S + \omega_0^2} \tag{5}$$

Comparing eqs (1),(2),(4) with this equation, we get

$$[\omega_0 / Q] = [GB_1 / R_2], \tag{6}$$

$$\omega_0^2 = [GB_1\ GB_2 / R_1], \tag{7}$$

$$1 = [(1/R_1)+(1/R_2)+(1/R_3)]. \tag{8}$$

Using these three equations, values of R_1, R_2, R_3 can be calculated for different values of Q and f_o. All these values are impedance scaled by 100 for practical realization with 1% tolerance of resistance

A practical solution is to design a network that has low sensitivity to element changes, thus sensitivities must be less than unity [2,4]. Using definition of sensitivity, the expression for this Q and ω_0 of this active-R filters are worked out and obtained in the form as given below

(i) $S^{\omega_0}_{R_1} = (-1/2)\left[1-\left(\omega_0^2 / GB_1\ GB_2\right)\right],$

(ii) $S^{Q}_{R_1} = (-1/2)\ 1+\left(\omega_0^2 / GB_1\ GB_2\right)\Big],$

(iii) $S^{\omega_0}_{R_3} = \left(\omega_0 / 2\ GB_1\ Q\right),$

(iv) $S^{Q}_{R_3} = \left[1-\left(\omega_0 / 2\ GB_1\ Q\right)\right],$

(v) $S^{Q}_{R_1} = S^{\omega_0}_{R_1}$

$$= (-1/2)\left[1-\left(\omega_0 / GB_1\ Q\right)-\left(\omega_0^2 / GB_1\ GB_2\right)\right],$$

vi) $S^{Q}_{GB_1} = S^{Q}_{GB_2} = -S^{\omega_0}_{GB_1} = -S^{\omega_0}_{GB_2} = -(1/2$

Thus, the passive sensitivities are all less than unity in magnitude and active sensitivities are half in magnitude.

Figure 1 shows the second order active-R filter with multiple feedback . The negative feedback at inverting input of first op.amp. is introduced through R_1 and R_2 and also the feedback is given at noninverting input of first op.amp. The two mA 741 op.amps. having identical gain bandwidth product (GB) are used. The performance of this circuit is studied for different values of Q (Q = 0.02,0.04,0.06,0.1,1 and 10); for the value of center frequency f_o = 10 KHz. Also, this circuit was studied for different center frequencies for Q = 1. Table 1 shows the resistance values for different Q. The general range of frequency response for this filter is from 10 Hz to 1MHz. The circuit was studied with variation in Q, and observed results are well matched with the designed values.

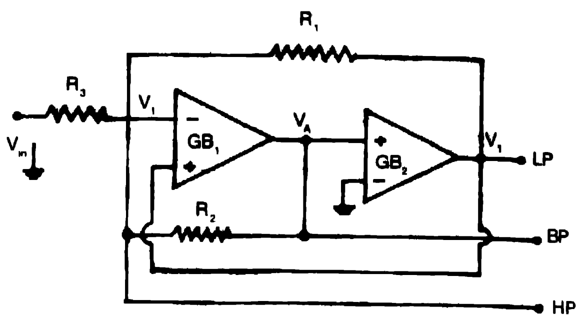

Figure 1. Circuit diagram of second order active-R filter with multiple feedback.

Table 1. Designed Values of resistances in KΩ

Q	R_1	R_2	R_3
0.02	310	0.110	0.930
0.04	310	0.220	0.180
0.06	310	0.330	0.140
0.10	310	0.550	0.120
1	310	5.6	0.100
10	310	56	0.100

Figure 2 shows the low pass (LP) response for different Q. It gives high passband gain and decreases with decrease in Q. It gives better gain roll-off (39dB/decade) for higher values of Q. For $Q \geq 1$, below 100 KHz and above 400KHz, the response coincides each other with small overshoot. This overshoot may appear for high values of Q [5].

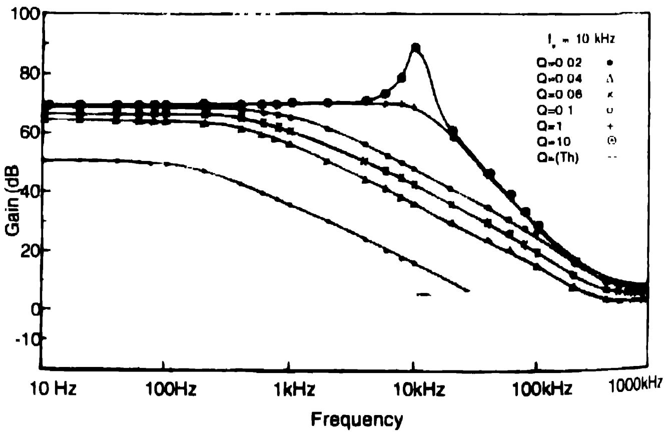

Figure 2. Low pass response for different Q.

Figure 3 shows band pass (BP) response for different Q. The bandwidth is controlled by Q. For high values of Q, this filter can be used for narrow bandwidth and low value of Q can be used for wide bandwidth. It has very good gain roll-off at lower frequencies.

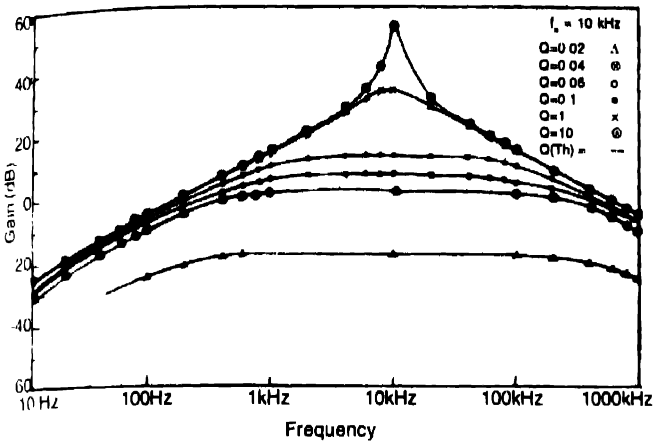

Figure 3. Band pass response for different Q

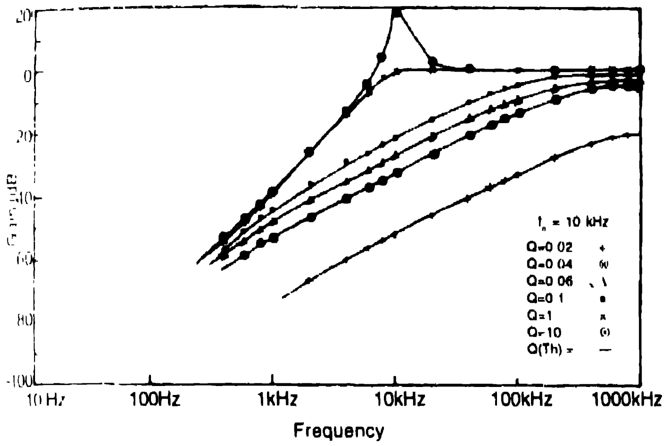

Figure 4. High pass response for different Q

Figure 4 shows high pass (HP)response for different Q. It shows excellent gain roll-off (40 dB/decade). The passband increases with increase in Q. Small overshoot appears for the higher values of Q.

The second order active-R filter with multiple feedback gives three basic filter functions; low pass, high pass and band pass at different terminals. It is suitable for high pass band gain and high value of Q. The band width is controlled by the value of Q with a lower limit on Q ($Q \geq 0.02$).

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